DEMONSTRATION OF OZONE TREATMENT FOR COOLING TOWERS AT THAYER HALL, U. S. MILITARY ACADEMY

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ABSTRACT

This report covers the evaluation of ozone as a stand-alone treatment in a new cooling tower system that has been in operation for two cooling seasons (summer only) at the U. S. Military Academy, West Point, New York. The results showed that ozone appeared to have protected the water contacted equipment from mineral scale and excessive micro-biological deposits but showed increased, excessive corrosion of both copper and mild steel. The use of ozone treatment for cooling towers appears to be somewhat effective as a biocide. However, the ozone residuals were too low and too great a fluctuation at Thayer Hall for optimum effectiveness. The life cycle cost analyses compared ozone treatment to conventional chemical treatment.

INTRODUCTION

The U.S. Army operates numerous cooling towers associated with chillers and other industrial processing systems. The water circulating through cooling towers can be the source of several costly operations and maintenance (O&M) problems such as biological fouling, scaling and corrosion.

These problems can waste energy by reducing the efficiency of heat transfer, and they can wear down or damage system components. Such problems are typically mitigated through the application of chemical treatments (i.e., biocides, antiscale compounds, and corrosion inhibitors), but the use of these chemicals poses its own set of problems.

Environmental compliance issues- some of the most effective compounds, such as chromates used for antiscale treatment, are considered hazardous and are banned or tightly restricted by the U.S. Environmental Protection Agency (EPA). Chemical costs arise from the fact that different chemicals are needed for each problem, and in the case of biocides, several chemicals are often required to destroy resistant microorganisms. Monitoring and maintenance have procedures which can be very labor-intensive to conduct, but failure to conduct them will shorten cooling system life cycle. Taken together, these problems make it highly desirable for the Army to find effective, cost-efficient alternative treatment methods for cooling tower water.

For almost l00 years ozone (O_3) has been recognized for its ability to disinfect water, but ozone has been used to treat cooling tower water only since the 1970s (U.S. Department of Energy 1995). Ozone treatment system manufacturers claim that ozone is more effective than chorine in destroying disease-causing bacteria such as strains linked to Legionnaires' disease. Ozone also is attractive from an environmental standpoint because it is a short-lived form that rapidly reverts to diatomic oxygen (O2), as opposed to chemical biocides, which concentrate in cooling systems over time and may contaminate public water treatment systems when purged via blowdown. Furthermore, anecdotal reports from ozone users and vendors suggest that ozone can control certain kinds of scale and corrosion. Consequently, interest in ozone as a stand-alone alternative to conventional chemical treatments has been growing. However, independent data are not available to substantiate the wide-ranging claims of ozone proponents.

To investigate ozone's effectiveness as a biocide in cooling towers as well as anecdotal claims about additional ozone benefits, the U.S. Army Construction Engineering Research Laboratories (USACERL) demonstrated and evaluated ozone water treatment technology on a new cooling tower installed at the U.S. Military Academy, West Point, NY. The research was conducted under the Army's Facilities Engineering Applications Program (FEAP). The objective of this project was to investigate the use of ozone as a stand-alone cooling water treatment at Thayer Hall (Building 601), U.S. Military Academy (USMA) at West Point, NY, and determine its effectiveness and cost-efficiency versus conventional chemical treatments.

EXPERIMENTAL PROCEDURES

To evaluate ozone as a stand-alone treatment, the technology's performance was monitored relative to industry standards for good protection of cooling tower system equipment. Good protection requires the prevention of scale due to water-soluble minerals, corrosion control of all system metals, micro-biological organism control and control of deposits from materials suspended in the system water. This investigation included all of the following evaluation techniques: system water analysis, corrosion rate determinations, micro-biological analysis, deposit accumulation rates and equipment inspections.

A bypass test loop shown in Figure 1, was installed around the two pumps in the circulating water system. The loop contained insertion points for two linear polarization corrosion monitor probes and eight metal specimens for corrosion monitoring, plus one BI°GEORGETM electrode for micro-biological monitoring.

Figure 1. Schematic of test loop.

To collect baseline data, one site visit was made before ozone was fed into the system for the 1993 air conditioning season. Three site visits were made during the 1993 air conditioning season to collect data, remove and replace the steel corrosion-test coupons, remove and replace chart paper, and collect water and deposit samples for laboratory analysis. Any cooling system equipment that was accessible during the site visits was inspected-primarily the cooling tower and basin. The condenser portion of the chiller and circulating water line interiors were not available for inspection either before, during, or after the cooling season.

Site inspections were performed by Puckorius & Associates, Inc., Evergreen, CO. Water analyses and corrosion rate determinations were performed in the Puckorius laboratory. Deposit analyses were performed by a subcontractor laboratory, Structural Integrity Associates, Inc., of San Jose, CA. Ozone analyses of cooling water were performed on-site using the indigo-trisulfonate calorimetric method (Method #8311, Hach Co., Loveland CO 80539).

Physical Plant and Ozone Generator Data

Cooling System -The cooling tower system provides cooling water for the heating, ventilating, and air conditioning (HVAC) system at Thayer Hall. It consists of two York 900 ton absorption refrigeration machines, which are used one at a time. The condenser tube material is 95-5 copper-nickel. Condenser tube sheets are mild steel, as are the water boxes and all circulating piping. Valves are mild steel, and circulating pump housings are cast iron with bronze impellers.

This cooling system utilizes three 300 ton Marley cross-flow galvanized-steel towers with stainless steel basins. The three basins are connected to a common suction (supply) header. Fill is honeycombed film-fill polyvinyl chloride (PVC); fan blades are aluminum. Design temperature drop of hot to cold water through the cooling towers is 16 °F, but can range from 14 °F to 23 °F. The return water is proportioned to both ends of the three towers. See Figure 2. Each tower has a circulating water capacity of 870 gallons per minute (gpm). Thus, 2610 gpm of water is recirculated when the system is operating.

Figure 2. Schematic of cooling system.

Ozone Generator- The ozone generator was supplied by Advanced Oxidation Systems, Inc. of Wayne, NJ. The generator has a capacity of 6 lb of ozone per day. At a nominal circulation rate of 2700 8pm, the maximum theoretical concentration of ozone would be 0.185 ppm. However, the power on the generator was set below design, generally at about 50 percent of capacity. Consequently, a maximum of 0.09 to 0.10 ppm of ozone fed into the cooling water. Ozone analyses on tower sump water ranged from 0.02 to 0.05 ppm.

Ozone Feed System- The feed system utilizes a unique ozone-lift mixing system as seen in Figure 3. The ozone-air mixture from the generator is fed into a venturi that draws water from the tower sump and lifts it into a mixing chamber. The mixture of air and water has a slightly higher pressure (head) than the tower basin and therefore the water flows back into the tower basin. A vent from the mixing chamber to the top of the tower gets rid of the off-gas (nitrogen, air, and some ozone) to the atmosphere.

Two cooling towers are fed by this system. The third tower had been fed by means of an inline static mixer shown in Figure 4. However, this arrangement allowed water to flow back into the generator when the system was down, in spite of a backflow prevention loop, causing generator damage.

Figure 3. Schematic of "ozone-lift" mixing system.

Figure 4. Schematic of inline static mixer.

RESULTS

DATA COLLECTED

Water Analyses- Makeup water samples were taken at the same time as the tower water samples in order to calculate the mineral relationships. The makeup water is a corrosive water with low hardness and low alkalinity, typical of Catskill-area surface water. The May 11th cooling tower water sample, taken before the ozone feed was started, had only been concentrated about two times, but the calcium and magnesium values were higher than can be accounted for by two cycles of concentration (COC). This indicates that scale deposited in the previous year, during no-treatment conditions, was being dissolved by the water. The Langelier Saturation Index (LSI), the Ryznar Stability Index (RSI), and the Puckorius Scaling Index (PSI) can indicate whether tower water is corrosive, i.e., non-scale-forming (Puckorius, September 1983). All three indices showed the water to be non-scale-forming.

The June 22nd cooling tower water sample which was taken 2 weeks after ozone feed was begun, showed about 7 COC. Calcium, alkalinity, and silica were precipitating and causing deposits. The more soluble magnesium, chloride, and sulfate ions were concentrating somewhat linearly. The LSI indicates that the circulating water was only slightly scale-forming at +1.12, assuming that an LSI of 0.00 is theoretically neither scale-forming nor scale-dissolving. However, experience has shown that a stable water may have an LSI between +1.0 and +2.0 without forming scale. Therefore, according to the LSI, the water sampled on 22 June is very nearly stable-neither scale-forming nor scale-dissolving. The RSI also indicates that the water is very nearly stable (approximately 6.0). The PSI, also approximately 6.0, shows it to be slightly scale-dissolving (slightly corrosive). The reason that the analysis of this concentrated water calculates as non-scale-forming is that some calcium and alkalinity ions have come out of solution as calcium carbonate and caused deposits, and the calculations for the indices reflect this. The water had become supersaturated with calcium and alkalinity upon concentrating, but as the calcium carbonate came out of solution, the water remained saturated with these ions (but seemingly stable).

The July 20th and August 5th cooling tower water samples, taken during routine ozone treatment, show high concentrations of magnesium, chloride, and sulfate, but lower concentrations of calcium, alkalinity, and silica. The various calcium carbonate scaling indices indicate a near-stable water, but at 15 and 19 COC this indication is not likely to be accurate. Calcium and alkalinity had precipitated out, forming deposits, and this is typical of ozone-treated tower waters. White particles are generally found in the basins of the towers, and may result in some scale on the heat exchange surfaces of the condenser, and often on the cooling tower fill. Examination was limited with the condenser not being inspected, and the cooling tower did not show appreciable deposits.

If one was to calculate a theoretical scaling index using the same number of concentrations of calcium and alkalinity as there are COCs of chlorides, the PSI for the 20 July sample would be 3.38. This is an extremely scale-forming value-one that would require an extremely high application of anti-sealant in a chemical treatment program. Even then, an anti-sealant might not work. Therefore it can be concluded that scale was being deposited within the cooling tower system.

The theoretical PSI for the 5 August sample calculates as 4.66-again a severe scale-forming condition, while the actual PSI (6.43) was non-scaling. A simple deposit analysis showed some effervescence from calcium carbonate on the mild steel test coupons when they were cleaned, but there was no reported loss of efficiency due to scaling in the operation of the chiller. Because there are two chillers operating alternately, not together, it is not known if there have been deposits within either of the condensers, or to what degree. The condensers were to be examined for scale when they are opened during the Winter of 1993-1994. No data have been obtained.

Corrosion Study-Corrosion monitoring methods used in this study were indirect, and utilized both corrosion coupons of mild steel (representing the water lines and condenser tube sheet and water box); copper (typical of condenser tubing but not found at USMA); galvanized mild steel (cooling tower components); Admiralty brass (70% copper and 30% zinc-also typical of condenser and other heat exchanger tubing, but not found at USMA); copper (95%) nickel (5%), which is not typical for condenser tubes but found in the condensers at USMA; copper (90%) nickel (10%), also not normal for condenser tubes and not used at USMA; and aluminum grade AL 1100 (not common in cooling water systems and not used at West Point). The metals not used at USMA were included in the study for possible reference to metals used at other Army installations.

Another indirect corrosion monitoring technique used a linear polarization monitor that provides instantaneous corrosion rate testing. A mild steel probe was utilized on this device. A third monitoring method was used to detect specific micro-biological-caused corrosion. This method employed a specialized linear polarization monitor system called the BI°GEORGETM biofilm monitor. Table 1 summarizes the results.

Results for Mild Steel- The test coupons were all heavily encrusted with small carbuncles of iron oxide when removed, and even had copper plated on the metal surfaces. When cleaned, all coupons showed active corrosion, including pitting. For mild steel, general corrosion rates of 5 to 7 mils per year (mpy) may be acceptable in some cooling tower systems. However, pitting corrosion in excess of these rates is unacceptable. Therefore, the results were clearly unacceptable for mild steel.
The corrosion monitor for mild steel read about halfway between the zero and 10 mpy (4-6 mpy) on the chart, which is about the same rate calculated for the test coupons. However, the monitor results did not track the actual metal loss apparent on the test coupons, possibly as the result of iron oxide accumulation on the monitor electrodes. Nevertheless, results were unacceptable because general corrosion rates were high and pitting corrosion was evident.

Results for Copper Alloy- All of the copper, Admiralty brass, and copper-nickel coupons were covered with a dark brown loosely adherent coating. Except for the copper-nickel samples, all ozone-exposed samples were darker than the same metal coupons exposed to standard cooling water treatments. This dark color indicates excessive corrosion. Copper alloys that are adequately protected will be clean and close to original color and appearance. Corrosion rates of greater than 0.1 mpy for copper, Admiralty brass, and copper-nickel are unacceptable.

The results of corrosion coupons (Table 1) show copper to be high (0.18-0.34 mpy); and not acceptable. Admiralty brass corrosion was excessive (0.34-0.51 mpy); and thus not acceptable. Copper/nickel was only slightly high at 0.13 mpy, which is acceptable. Galvanized steel and aluminum coupons looked even worse than their measured corrosion rates of 5 and 7 mpy, respectively. Attack was so that neither metal should be considered for use with ozone.
Only the two stainless steel coupons had corrosion rates that would be considered acceptable, at 0.080 mpy for 304 stainless and 0.103 for 316 stainless. A large amount of red iron oxide was found in the stainless pans of the towers, about 0.125 in. deep. Some white particles were separated from a deposit sample and analyzed by energy dispersive x-ray. The white particles were composed of zinc (probably as zinc carbonate), calcium (probably as

calcium carbonate and calcium silicate), silica, and iron and copper corrosion products. The deposit, as found, analyzed as iron, copper, and zinc corrosion products, plus calcium as the carbonate, as indicated by effervescence in acid.

Table 1. Summary of corrosion coupon results.

Micro-biological Study- The micro-biological monitoring was performed by Structural Integrity Associates (SIA), Inc., of San Jose, CA under subcontract to Puckorius & Associates, Inc A portion of the testing was conducted using a device called the BI°GEORGETM micro-biological corrosion monitor; the results were tracked for experimental purposes to compare with the conventional test methods employed.

The BI°GEORGETM corrosion monitor, which uses a mild steel probe, showed that little or no biofilm had grown during the exposure period, but some big-corrosion was detected. Active corrosion-causing microbes were found on the probe, which showed considerable corrosion fluctuation and some pitting. This suggests that (1) big-corrosion had occurred during the exposure period and (2) ozone residuals had probably varied considerably from high levels to none. While the BI°GEORGETM probe indicated relatively high counts of bacteria present in the cooling water, conventional testing of wetted tower surfaces revealed no biofilm growth.

COST ANALYSIS AND OBSERVATIONS

LIFE-CYCLE COST ANALYSIS

Based on the field investigations made at Thayer Hall, reduced scaling will allow tower pumps to run more efficiently and with less maintenance. Increased efficiency of equipment will reduce energy requirements and electrical use. With less scale buildup in the lines, heat transfer also will improve. In addition to better heat transfer and reduced energy needs, the use of chemicals is eliminated and the required amount of makeup water is reduced. The annual estimated savings for Army-wide application is approximately $2.25 million. Table 2 summarizes the potential savings reported in Appendix C.

Table 2. Estimated life-cycle cost savings for ozone treatment (versus conventional methods).

OBSERVATIONS

Scale and Deposits- There has been no indication of scale on heat exchange surfaces (condenser) due to loss of efficiency, but there has been no inspection of the condenser for verification. Deposits were found in the cooling tower and basin. These were analyzed and showed both scale deposits (calcium and silica) as well as corrosion products (iron oxide); copper (from condenser tubes); and zinc (from galvanized steel cooling tower).

Micro-biological Growth- No apparent biological deposits were found in the towers at Thayer Hall during the site visits. However, two other methods for monitoring micro-biological organisms and deposits were utilized. One method was the incubation of cooling water samples to determine the levels of microbes present. The use of MIC kits (Big-industrial Technologies) revealed the presence of slime-forming (deposit-producing) bacteria and corrosive bacteria (anaerobic and acid-producing). The second method was to culture deposits found on the BI°GEORGETM biofilm probe. This method detected the same micro-organisms found in the water samples. The analysis showed levels of 105 and 106 CFU (colony-forming units) per milliliter of sample. Good levels of microbiological control range from 103 to 104 CFU/ml, so the levels detected in the water samples and on the biofilm probe in this demonstration were too high to be considered good.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions for the USMA ozone technology demonstration are as follows:

- Ozone performed satisfactorily at Thayer Hall as a stand-alone biocide, but two separate testing modes detected micro-biological deposits in excess of levels normally considered desirable, and some test coupons exhibited microbe-induced corrosion.
- Scale deposits occurred during the demonstration, but no loss in system efficiency was detected. Cooling tower deposits may require frequent cleaning, however.
- Corrosion-especially pitting-was excessive and unacceptable for mild steel, galvanized steel, copper, Admiralty brass (90% copper, 10% zinc), and aluminum.

- Corrosion of copper/nickel alloy was low and acceptable.
- Corrosion of stainless steel was negligible.
- Ozone residuals generally were too low during the demonstration period, and fluctuated too much for optimum water treatment effectiveness.

The Thayer Hall cooling system contains mild steel (lines), galvanized steel (cooling tower), and copper/nickel (condenser tubing). Based on the final condition of test coupons made of mild steel and galvanized steel, it can be concluded that the lines and cooling tower experienced unacceptable corrosion rates during the demonstration treatment. This conclusion implies that continuous ozone treatment of the cooling water in the Thayer Hall system would cause premature leaks, requiring early repair or possible replacement. Based on the test findings for the copper/nickel test coupons, it may be concluded that condenser tubing stayed within acceptable corrosion rates.

It is concluded that ozone cannot serve as a stand-alone cooling water treatment for the USMA Thayer Hall cooling system, or for other systems elsewhere that are similar in terms of material composition and makeup water. USMA's dual-chiller design could provide uninterrupted cooling service to Thayer Hall using ozone treatment, but only if USMA were to make a larger investment in labor and materials for cleaning. Furthermore, because the Thayer Hall system principally comprises metals that performed poorly in ozone exposure, stand-alone ozone treatment of the cooling water would create a higher risk of equipment damage or premature failure due to corrosion.

In summary, it is concluded that ozone technology as a stand-alone water treatment technology cannot offer the required corrosion protection provided by standard multiple chemical treatments. It is further concluded that site-specific conditions must be considered to correctly determine whether ozone treatment can either partially or entirely replace standard chemical treatments for cooling tower water. Guidelines are available in the literature (e.g., Puckorius, September 199l) that could help other Army installations determine whether ozone treatment is a useful, cost-effective alternative to standard methods.

Recommendations

It is recommended that the ozone feed system at Thayer Hall be improved to provide better, more reliable feed and delivery. It is further recommended that the system be monitored frequently enough by operations personnel to detect and correct wide fluctuations in ozone residual levels. Also, it is recommended that a longer mixing chamber, such as on the tower at the Officers's Club, be installed on the Thayer Hall system.

REFERENCES

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2. Puckorius, P.R, "Ozone for Cooling Towers: Is it a Panacea?" Paper #212, national Association of Corrosion Engineers Annual Conference and Corrosion Show, Cincinnati OH, 11-15 March 1991.
3. Puckorius, P.R, "Ozone Use in Cooling Tower Systems: Current Guidelines-Where it Works," International Ozone Association, Pan American Committee, Toronto, Ontario, 16-18 September 1991.

Table 1. Summary of corrosion coupon results.

Coupon #	Exposure Dates	# Of Days	Weight Loss	MPY
T7921	06/23/93-07/20/93	27	0.2058 gram	6.35
T7922	06/23/93-08/05/93	45	0.3023	5.86
T2926	07/20/93-08/05/93	16	0.4638	24.15
T2923	06/23/93-10/25/93	124	0.6523	4.38
T2928	08/05/93-10/25/93	81	0.6971	7.07
T2929	08/05/93-10/25/93	81	0.7017	7.22

Copper - Grade CDA 110 (f = .737)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
1811	06/23/93-07/20/93	27	0.0099 gram	0.270
1812	06/23/93-08/05/93	43	0.0103	0.187
D2108	07/20/93-08/05/93	16	0.0074	0.341
D2109	08/05/93-10/25/93	81	0.0211	0.192
D2110	08/05/93-10/25/93	81	0.0233	0.212

Admiralty-Grade CDA443 (f = .769)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
A632	06/23/93-07/20/93	27	0.0122 gram	0.347
A939	07/20/93-08/05/93	16	0.0105	0.515

95:5 Cu:Ni Grade 704 (f = .733)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
01	08/05/93-10/25/93	81	0.0144 gram	0.130

304 Stainless (f = .826)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
04	06/23/93-07/20/93	27	0.0026	0.080

316 Stainless (f = .826)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
A1246	07/20/93-08/05/93	16	0.0021	0.103

Galvanized Steel (f = .833)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
52	06/23/93-07/20/93	27	0.1614	4.98

Aluminum Grade AL1100 (f = 2.419)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
A0503	08/05/93-10/25/93	81	0.2368	7.07

90:10 Cu:Ni Grade 706 (f = .733)

Coupon #	Exposure Dates	# of Days	Weight Loss	MPY
01	08/05/93-10/25/93	81	0.147	0.133

Table 2. Estimated life-cycle cost savings for ozone treatment (versus conventional methods).

Cost Category	**Savings**
MAINTENANCE SAVINGS	$34K
ENERGY REDUCTION SAVINGS	$1660K
ELIMINATION OF CHEMICALS	$360K
REDUCTION OF MAKEUP WATER	$200K
TOTAL ANNUAL SAVINGS ARMY WIDE	**$2250K**